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Image Segmentation of Damage in Integrated Structural Health Monitoring

NASA NRA: Integrated Probabilistic Diagnosis and Prognosis for Airframe Structural Health Management

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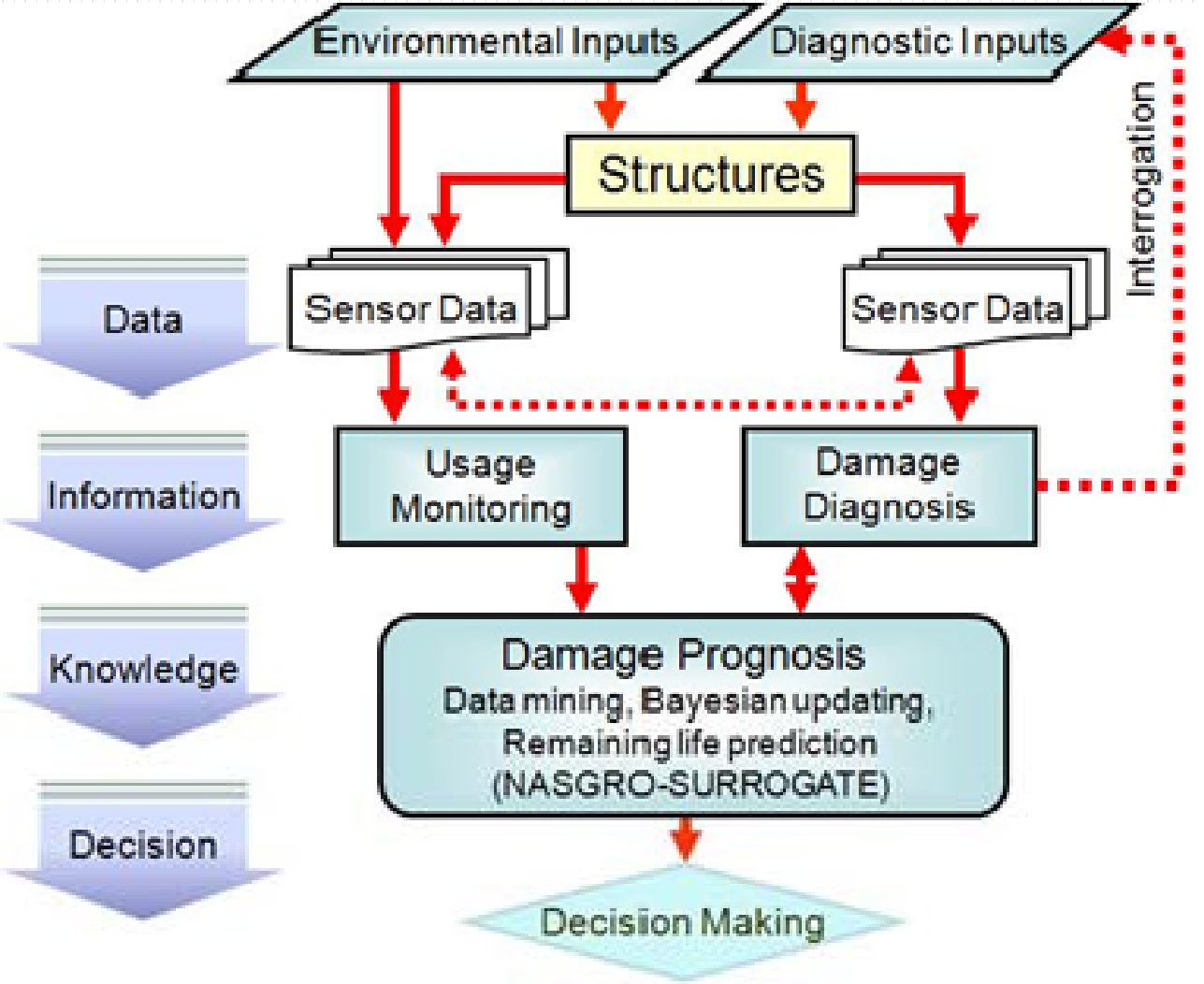
Content

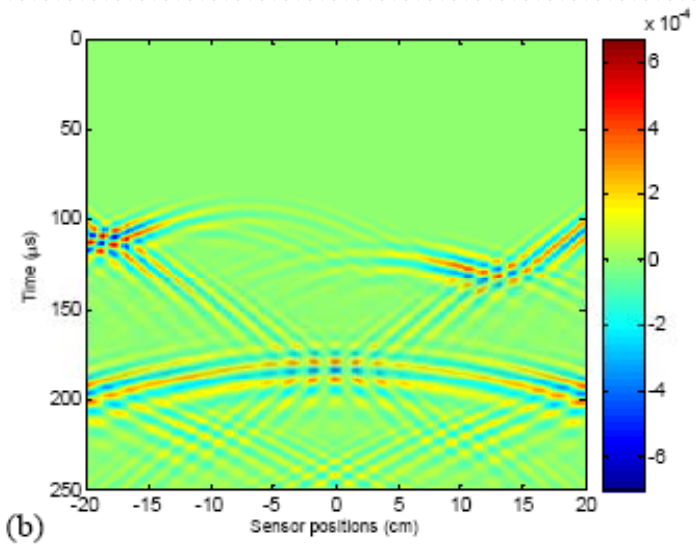
- **Why Bayesian image segmentation?**
- **What is Bayesian Image segmentation?**
- How Bayesian theorem works?
  (Markov parameters)
- **Results and beyond.**

Basic SHM architecture

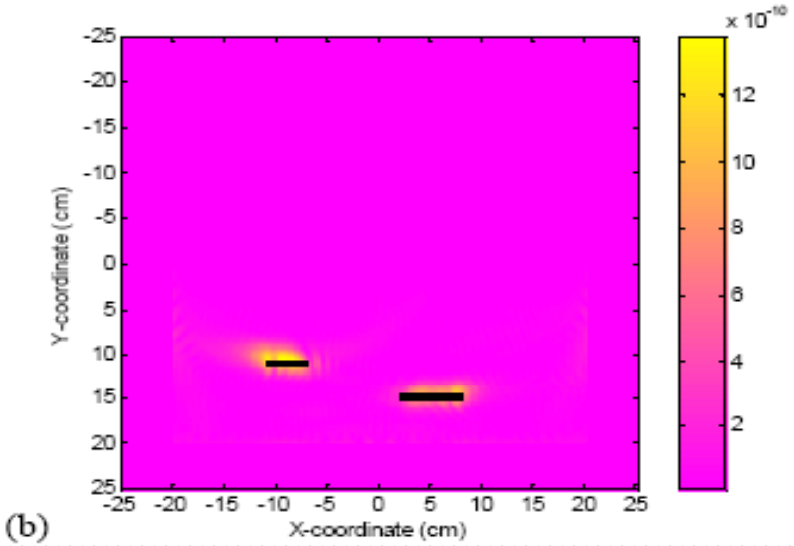


Damage Diagnosis

- Develop a robust damage imaging technique using an array of piezo sensors/actuators
- Develop a migration method for imaging the damage in the frequency domain called f-k migration, rather than time-domain (near real-time)



Sensor data plot



Damage Imaging

Image using Ultrasonic Spectroscopy (L. Harmon et al., Cleveland State U., SPIE 4704)

Poor image quality of damage of PMC by speckle noise (micro-heterogeneities)

1. Can we provide an automated procedure for segmenting out the crack?
2. Can we combine images from different techniques or from past times to enhance the damage image and quantify the severity of the crack?

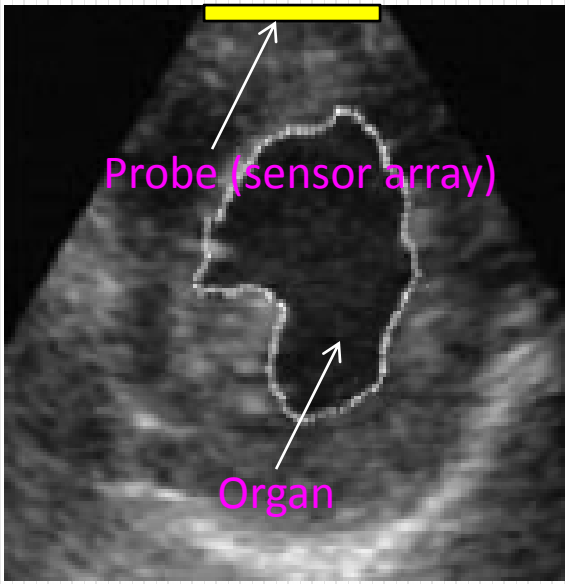
Why Bayesian image segmentation?

- In damage diagnosis, the damage imaging can be formed either by migration technique or NDE techniques. However in Damage Prognosis, extract and quantify damage information (like crack length, severity) are required to predict the remaining life of structures. (Paris law, NASGRO)
- Similar to the medical imaging field, image segmentation can be used for damage imaging provided by migration technique.
- Bayesian statistics **combines** ***the current image*** with ***the priori knowledge*** (such as spatial constraint, previous result and pre-known structure properties) to obtain robust and enhanced damage evaluation.

Ultrasound based imaging

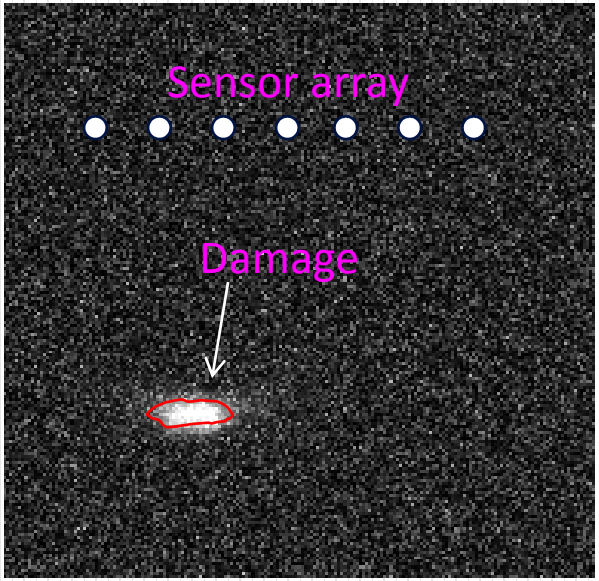
Medical segmentation aims at image-guided interventions and therapy

HUMAN BODY



Medical imaging

AIRCRAFT



SHM imaging (metals)

Damage segmentation aims at remaining life prediction and mitigation

What is Bayesian image segmentation?

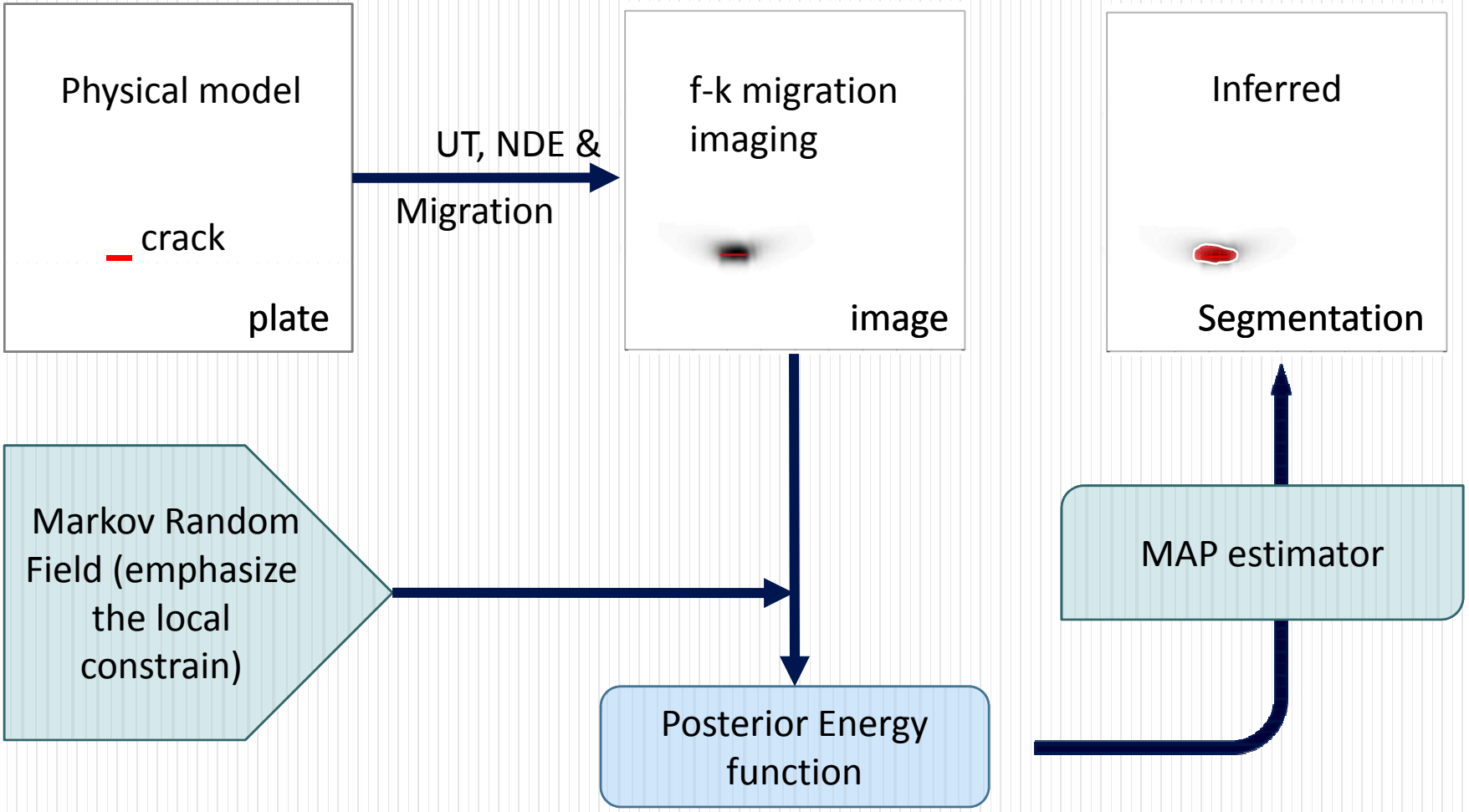
- According to the Bayesian rule

$$posterior = \frac{likelihood \times prior}{evidence}$$

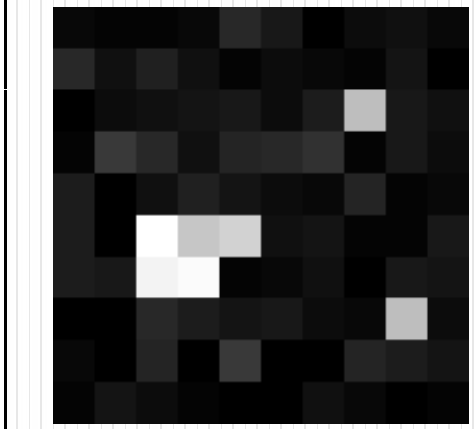
  - Likelihood
    - The current image or data.
  - Prior
    - Previous result, assumptions and structural geometries.

- Maximum a Posteriori (MAP)
  - Problem can be state as following: given y, estimate x, which maximize the posteriori probability p(x|y)

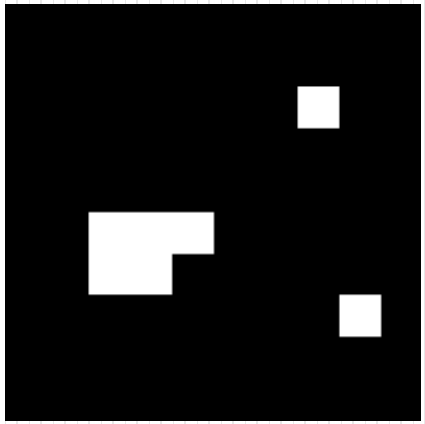
How Image Segmentation works based on Bayesian Framework?



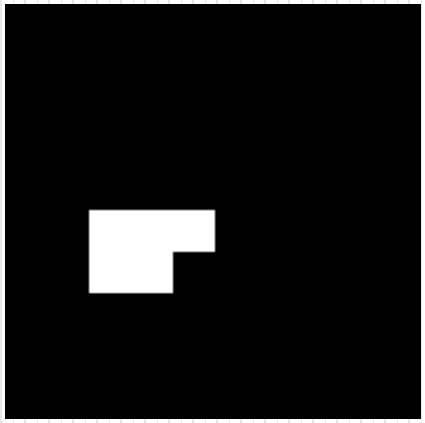
Illustrative example (speckle elimination)



Original image



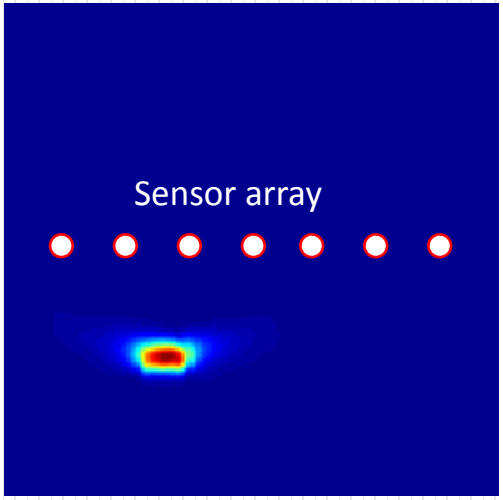
K-means

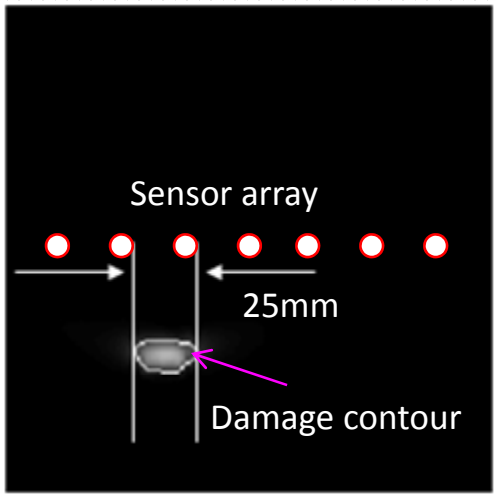


Bayesian updated

Segmentation for f-k migration image

Actual crack length	K-means	Bayesian
20.00mm	30.00mm	25.00mm

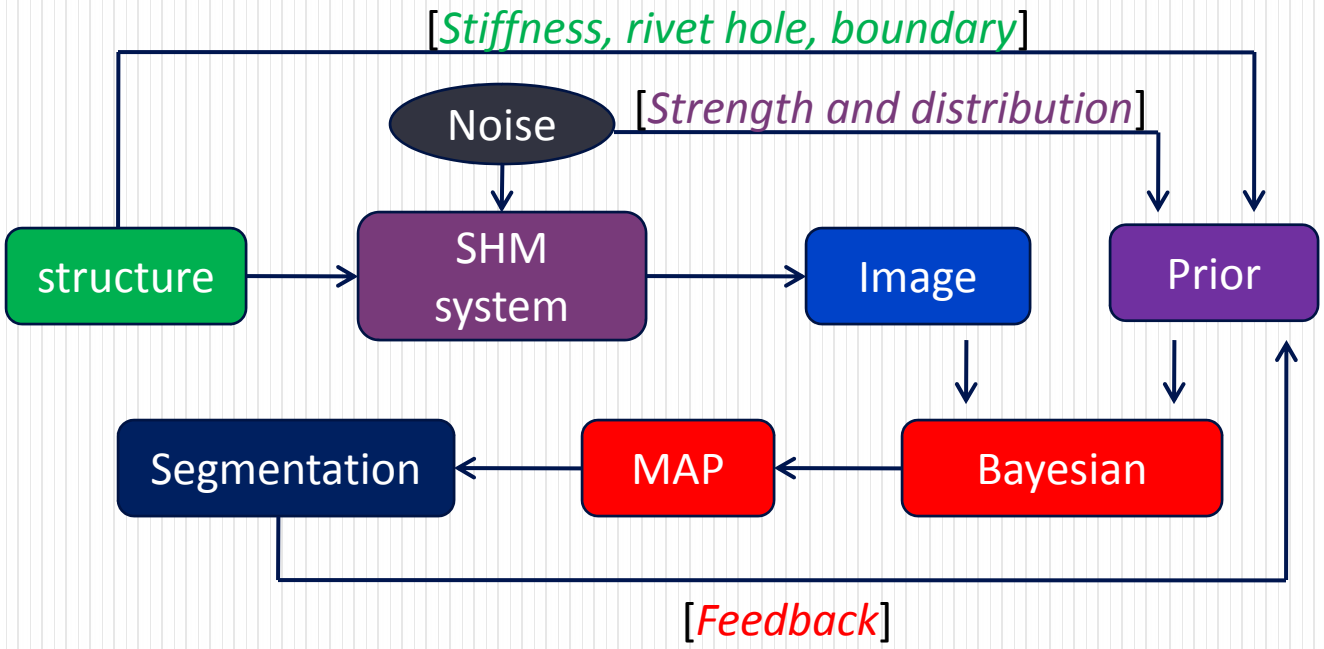




Refining the segmentation and adding the prior knowledge to provide more accurate crack information.

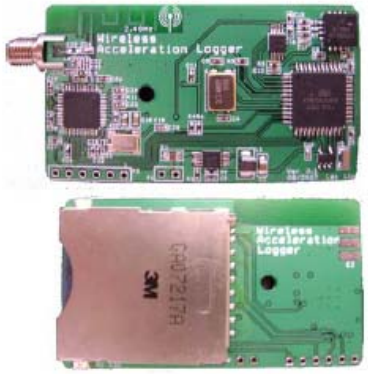
More priors

- More prior information including structural shape, previous segmentation.



North Carolina State University Wireless Sensor System

- Applied to an AF SRM transport shock measurement



Printed Circuit Boards

Assembly

Specification

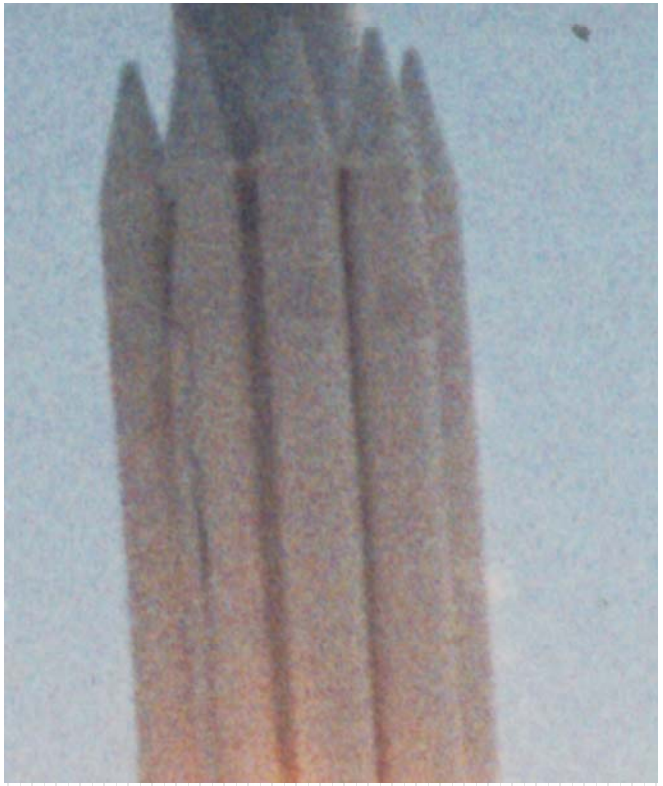
Wireless Protocol	Zigbee/IEEE802.15.4
ADC (internal)	10-bit, 8-ch, 15 Ksps
ADC (external)	12-bit, 4-ch, 1 Msps
Sensors	Accelerometer; Temperature.
Accelerometer Cutoff-freq. (Hz)	3-axis; ±6 g; 350(x, y), 150(z)
Temperature	-55˚C ~ 125 ˚C
Extension	Secure digital socket
Power supply	2.8 Wh Lithium
Estimated power consumption	38 mA – Active 50 µA – Sleep 8 mA – Average (250 Hz)
Estimated life	5 days (250 Hz, 4 Channels)
Dimension (inch)	2.5(w) x 2.2(h) x 1.4(t)

Features

- 3-Axis Acceleration Sensing
- Onboard Temperature Monitoring
- Secure Digital Card Expansion
- IEEE802.15.4 Wireless Network
- Low Power Consumption
- Long Service Life

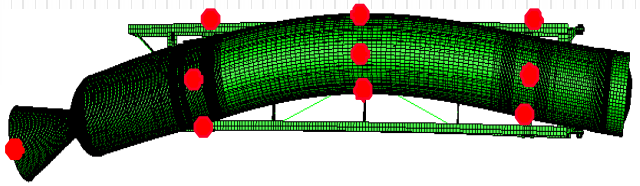
Applications

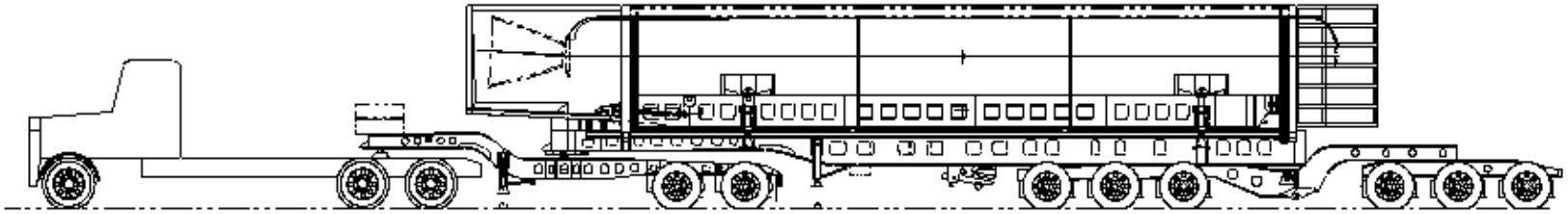
- Shock Monitoring
- Vibration Measurement
- Impact Analysis



Wireless Sensor Demonstration

- **An incident occurred last year during motor transport en route to a Florida storage site, in which cradle shock data exceeded requirement**
  - **No detailed data from shock logs for potential damage assessment**
- **NC State sensor system installed on a scrapped motor during shipment to White Sands**
  - **10 wireless sensors installed on non-interference basis and setting up receiving station within a few hours**
  - **Data downloaded from SD cards after reaching destination**
  - **Data confirm no violation in transport g limit**





Conclusion

- The presented Bayesian based segmentation with MRF prior can eliminate noise/speckles in the f-k migration images.
- This algorithm also improves the spatial constraint , eliminates the end tails in the image and give more accurate estimation of the crack size.
- Previous segmentation *using other imaging techniques* and structural shape is potential to be priors to update the segmentation for more robust results.

Prior model– Markov Random Field

- What is Markov Random Field (MRF) ?

  -- A random field with positive probability and following Markovian property is a MRF.

$$p(x_s \mid x_q, all\ q \neq s) = p(x_s \mid x_q, all\ q \in N_s)$$

- Hammersley-Clifford theorem

  Show the equivalence between MRF and Gibbs Random Field(GRF);

- Thus, MRF has a concrete mathematical potential representation (Gibbs energy density).